

## **RUBBER COMPOSITION CONTAINING FUNCTIONALIZED POLYMER NANOPARTICLES**

### **BACKGROUND OF THE INVENTION**

The present invention relates to polymer nanoparticles, methods for their preparation, and their use as, for example, additives for rubber and tire compositions. The invention advantageously provides mechanisms for surface modifications, functionalization, and general characteristic tailoring to improve performance in various  
5 host compositions.

Polymer nanoparticles have attracted increased attention over the past several years in a variety of fields including catalysis, combinatorial chemistry, protein supports, magnets, and photonic crystals. Similarly, vinyl aromatic (e.g. polystyrene) microparticles have been prepared for uses as a reference standard in the calibration of  
10 various instruments, in medical research and in medical diagnostic tests. Such polystyrene microparticles have been prepared by anionic dispersion polymerization and emulsion polymerization.

Nanoparticles can be discrete particles uniformly dispersed throughout a host composition. Nanoparticles preferably are monodisperse in size and uniform in shape.  
15 However, controlling the size of nanoparticles during polymerization and/or the surface characteristics of such nanoparticles can be difficult. Accordingly, achieving better control over the surface composition of such polymer nanoparticles also is desirable.

Rubbers may be advantageously modified by the addition of various polymer compositions. The physical properties of rubber moldability and tenacity are often improved through such modifications. Of course, however, the simple indiscriminate addition of nanoparticles to rubber is likely to cause degradation of the matrix material, i.e., the rubber, characteristics. Moreover, it is expected that primarily the selection of nanoparticles having suitable size, material composition, and surface chemistry, etc., will improve the matrix characteristics.

In this regard, development of nanoparticles having a outer layer which would be compatible with a wide variety of matrix materials is desirable because discrete particles could likely disperse evenly throughout the host to provide a uniform matrix composition. However, the development of a process capable of reliably producing acceptable nanoparticles has been a challenging endeavor. For example, the solubility of various monomers in traditional alkane solvents has made solution polymerization a difficult process by which to achieve nanoparticles having a variety of outer layers. Moreover, the development of a solution polymerization process producing reliable nanoparticles, particularly nanoparticles advantageously employed in rubber compositions, has been elusive.

Commonly owned U.S. Patent Number 6,437,050 is directed to polymer nanoparticles and a method of forming nanoparticles with desired surface characteristics and size. Commonly owned U.S. Patent Application Serial Number 10/223,393 (filed August 19, 2002) includes a method of controlling the surface characteristics of polymer nanoparticles via surface functionalization. In this application

the functional groups remain inside the nanoparticle in the form of an organic reaction residue.

Nano-scale metal composites have also been used advantageously in a variety of fields including, but not limited to, information technology, medicine and health, material and manufacturing, aeronautics and space exploration, environmental, and energy fields. Formation of nano-scale metal composites has often proven difficult due to the expense and difficulty of creating known templates, as well as the often difficult step of separating the composites from the template.

Accordingly, it would be desirable to develop polymer nanoparticles with desirable surface characteristics and size. It would also be desirable to develop a process for using these nanoparticles as templates to produce nano-scale metal composites.

## SUMMARY OF THE INVENTION

A polymer nanoparticle is provided. The nanoparticle includes an inner layer having alkenylbenzene monomer units. The nanoparticle further includes an outer layer having monomer units selected from conjugated dienes, alkylbenzenes, alkenylbenzenes, and mixtures thereof. The nanoparticle has at least one functional group associated with the outer layer.

A process for forming functionalized nanoparticles is also provided. The process includes polymerizing alkenylbenzene monomer and conjugated diene monomer in a hydrocarbon solvent to form a diblock polymer. After formation of the diblock polymer, micelles of the diblock polymer are formed. At least one crosslinking agent is added to

the micelles to form crosslinked nanoparticles having a poly(alkenylbenzene) core and an outer poly(conjugated diene) layer from the micelles. The poly(conjugated diene) layer is optionally hydrogenated to form nanoparticles containing a poly(alkenylbenzene) core and a polycrystalline outer layer. After formation, the nanoparticles are reacted with a compound including at least one functional group to form functionalized nanoparticles. The reaction may be carried out before or after hydrogenation.

According to a further embodiment, a polymer nanoparticle including a poly(alkynylbenzene) core, a copolymer outer layer and at least one functional group attached thereto is also provided. The copolymer outer layer includes at least an alkenylbenzene monomer unit and a conjugated diene monomer unit. The nanoparticle has a mean average diameter less than about 100nm.

A process for forming a polymer nanoparticle with a copolymer outer layer and at least one functional group attached thereto is also provided. The process includes copolymerizing at least one alkenylbenzene monomer and at least one conjugated diene to form a random copolymer. After the polymerization is substantially completed, an additional charge of alkenylbenzene monomer is made and polymerized onto the copolymer chain ends to form a diblock copolymer. Micelles of the diblock copolymer are formed and at least one crosslinking agent is added to the polymerization mixture to form crosslinked nanoparticles. The nanoparticles have a mean average diameter less than about 100nm. After formation, the nanoparticles are reacted with a compound including at least one functional group to form functionalized nanoparticles.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 is a graph depicting the dynamic modulus ( $G'$ ) temperature dependence of rubber composition prepared in accordance with EXAMPLES 3, 4, and 5.

5        FIGURE 2 is a graph depicting the  $G'$  strain dependence of rubber particles prepared in accordance with EXAMPLES 3, 4, and 5.

FIGURE 3 is a TEM photograph of polymer nanoparticles formed in accordance with EXAMPLE 6.

10        FIGURE 4 is a TEM photograph of maleated polymer nanoparticles formed in accordance with EXAMPLE 7.

FIGURE 5 is a TEM photograph of metallized polymer nanoparticles formed in accordance with EXAMPLE 13.

FIGURE 6 is a TEM photograph of metal nanocomposites formed in accordance with EXAMPLE 13.

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## DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

### GENERAL NANOPARTICLE PROCESS OF FORMATION

20        One exemplary functionalized polymer nanoparticle of the present invention is formed from diblock polymer chains having at least a poly(conjugated diene) block and a poly(alkenylbenzene) block. The poly(alkenylbenzene) blocks may be crosslinked to form the desired nanoparticles. After nanoparticle formation, the resultant nanoparticles are reacted with an organic compound to form functionalized nanoparticles. The functionalized nanoparticles preferably have at least one functional group associated with an outer layer or on an exterior of the nanoparticle. The functionalized

nanoparticles have diameters – expressed as a mean average diameter – that are preferably less than about 100 nm, more preferably less than about 75 nm, and most preferably less than about 50 nm. The nanoparticles preferably are substantially monodisperse and uniform in shape. The dispersity is represented by the ratio of  $M_w$  to  $M_n$ , with a ratio of 1 being substantially monodisperse. The polymer nanoparticles of the present invention preferably have a dispersity less than about 1.3, more preferably less than about 1.2, and most preferably less than about 1.1. Moreover, the nanoparticles are preferably spherical, though shape defects are acceptable, provided the nanoparticles generally retain their discrete nature with little or no polymerization between particles.

The nanoparticles are preferably formed via dispersion polymerization, although emulsion polymerization is also contemplated. Hydrocarbons are preferably used as the dispersion solvent. Suitable solvents include aliphatic hydrocarbons, such as pentane, hexane, heptane, octane, nonane, decane, and the like, as well as alicyclic hydrocarbons, such as cyclohexane, methyl cyclopentane, cyclooctane, cyclopentane, cycloheptane, cyclononane, cyclodecane and the like. These hydrocarbons may be used individually or in combination. However, as more fully described herein below, selection of a solvent in which one polymer forming the nanoparticles is more soluble than another polymer forming the nanoparticles is important in micelle formation.

With respect to the monomers and solvents identified herein, nanoparticles are formed by maintaining a temperature that is favorable to polymerization of the selected monomers in the selected solvent(s). Preferred temperatures are in the range of about -40 to 250 °C, with a temperature in the range of about 0 to 150 °C being particularly

preferred. As described in more detail below, the interaction of monomer selection, temperature, and solvent facilitates the formation of block polymers which form micelles and ultimately the desired nanoparticles.

According to one embodiment of the invention, a diblock polymer is formed of  
5 vinyl aromatic hydrocarbon monomers and conjugated diene monomers in the hydrocarbon solvent. The diblock polymer contains at least a first end block that is soluble in the dispersion solvent, preferably a conjugated diene monomer, and at least a second end block which is less soluble in the dispersion solvent, preferably a vinyl-substituted aromatic hydrocarbon monomer. Moreover, in one preferred embodiment, a  
10 vinyl-substituted aromatic hydrocarbon monomer is chosen, the polymer of which is generally insoluble in the dispersion solvent.

As is known in the art, such a diblock copolymer may be formed by living anionic polymerization, in which a vinyl-substituted aromatic hydrocarbon monomer is added to a completely polymerized conjugated diene monomer. Another method of forming  
15 substantially diblock polymers is the living anionic copolymerization of a mixture of monomers, such as a conjugated diene monomer and a vinyl-substituted aromatic hydrocarbon monomer in a hydrocarbon solvent, particularly, in the absence of certain polar additives, such as ethers, tertiary amines, or metal alkoxides which could otherwise effect the polymerization of the separately constituted polymer blocks. Under  
20 these conditions, the conjugated diene generally polymerizes first, followed by the polymerization of the vinyl-substituted aromatic hydrocarbon. Of course, certain advantages, as described below may be achieved via a random polymerization of at least one block of the polymer.

Nonetheless, it is generally preferred that a vinyl substituted aromatic hydrocarbon polymerize last, positioning the living end of the polymerizing polymer on a vinyl aromatic block to facilitate later cross-linking.

Such copolymers, formed by either method, are believed to aggregate to form micelle-like structures with, for example, vinyl-substituted aromatic blocks directed toward the centers of the micelles and conjugated diene blocks as tails extending therefrom. It is noted that a further hydrocarbon solvent change or a decrease in polymerization mixture temperature may also be used, and may in fact be required, to obtain formation of the micelles. Moreover, these steps may be used to take advantage of the general insolubility of the vinyl-aromatic blocks. An exemplary temperature range for micelle formation is between about 40 and 100 °C, more preferably between about 50 and 80 °C.

After the micelles have formed, additional conjugated diene monomer and/or vinyl-substituted aromatic hydrocarbon monomer can be added to the polymerization mixture as desired.

After formation of the micelles, a cross-linking agent is added to the polymerization mixture. Preferably, a crosslinking agent is selected which has an affinity to the vinyl-substituted aromatic hydrocarbon monomer blocks and migrates to the center of the micelles due to its compatibility with the monomer units and initiator residues present in the center of the micelle and its relative incompatibility with the dispersion solvent and monomer units present in the outer layer of the micelle. The crosslinking agent crosslinks the center core of the micelle (i.e. alkenylbenzene) to form the desired nanoparticle. Consequently, nanoparticles are formed from the micelles



with a core including, for example, styrene monomer units and a outer layer including, for example, butadiene monomer units.

The conjugated diene monomers contemplated for the block polymer are those soluble in non-aromatic hydrocarbon solvents. C<sub>4</sub>-C<sub>8</sub> conjugated diene monomers are the most preferred. Exemplary conjugated diene monomers include 1,3-butadiene, isoprene, 1,3-pentadiene, 2,3-dimethyl-1,3-butadiene, 1,3-hexadiene, 2-methyl-1,3-pentadiene, 3,4-dimethyl-1,3-hexadiene, 4,5-diethyl-1,3-octadiene, phenyl-1,3-butadiene, and mixtures thereof. An especially preferred conjugated diene is 1,3-butadiene.

Vinyl-substituted aromatic hydrocarbon monomers include styrene,  $\alpha$ -methylstyrene, 1-vinyl naphthalene, 2-vinyl naphthalene, 1- $\alpha$ -methyl vinyl naphthalene, 2- $\alpha$ -methyl vinyl naphthalene, vinyl toluene, methoxystyrene, t-butoxystyrene, and the like, as well as alkyl, cycloalkyl, aryl, alkaryl, and aralkyl derivatives thereof, in which the total number of carbon atoms in the combined hydrocarbon is not greater than 18, as well as any di- or tri-vinyl substituted aromatic hydrocarbons, and mixtures thereof.

The diblock polymer, preferably has M<sub>w</sub> of about 5,000 to 200,000, more preferably between about 10,000 and 100,000. A typical diblock polymer will be comprised of 5 to 95% by weight conjugated diene and 5 to 95% by weight vinyl-substituted aromatic hydrocarbon, more preferably 20 to 80% by weight, and most preferably 50 to 60% by weight of each contributed monomer type.

The micelle formed by the polymerization of vinyl-substituted aromatic hydrocarbons and conjugated diene monomers is preferably crosslinked to enhance the uniformity and permanence of shape and size of the resultant nanoparticle. Preferred

crosslinking agents are di- or tri-vinyl-substituted aromatic hydrocarbons. However, crosslinking agents which are at least bifunctional, wherein the two functional groups are capable of reacting with vinyl-substituted aromatic hydrocarbon monomers are acceptable. A preferred crosslinking agent is divinylbenzene (DVB).

5           A 1,2-microstructure controlling agent or randomizing modifier is optionally used to control the 1,2-microstructure in the conjugated diene contributed monomer units, such as 1,3-butadiene, of the nanoparticle. Suitable modifiers include hexamethylphosphoric acid triamide, N,N,N',N'-tetramethylethylene diamine, ethylene glycol dimethyl ether, diethylene glycol dimethyl ether, triethylene glycol dimethyl ether, 10 tetraethylene glycol dimethyl ether, tetrahydrofuran, 1,4-diazabicyclo [2.2.2] octane, diethyl ether, triethylamine, tri-n-butylamine, tri-n-butylphosphine, p-dioxane, 1,2-dimethoxy ethane, dimethyl ether, methyl ethyl ether, ethyl propyl ether, di-n-propyl ether, di-n-octyl ether, anisole, dibenzyl ether, diphenyl ether, dimethylethylamine, bis-oxalanyl propane, tri-n-propyl amine, trimethyl amine, triethyl amine, N,N-dimethyl 15 aniline, N-ethylpiperidine, N-methyl-N-ethyl aniline, N-methylmorpholine, tetramethylenediamine, oligomeric oxalanyl propanes (OOPs), 2,2-bis-(4-methyl dioxane), and bistetrahydrofuryl propane. A mixture of one or more randomizing modifiers also can be used. The ratio of the modifier to the monomers can vary from a minimum as low as 0 to a maximum as great as about 4000 millimoles, preferably about 20 0.01 to 3000 millimoles, of modifier per hundred grams of monomer currently being charged into the reactor. As the modifier charge increases, the percentage of 1,2-microstructure (vinyl content) increases in the conjugated diene contributed monomer units in the outer layer of the polymer nanoparticle. The 1,2-microstructure content of

the conjugated diene units is preferably between about 5 and 95%, more preferably between about 1 and 99%.

Without being bound by theory, it is believed that an exemplary micelle will be comprised of ten to five hundred diblock polymers yielding, after crosslinking, a  
5 nanoparticle having a  $M_w$  of between about 5,000 and 10,000,000, preferably between about 5,000 and 4,500,000.

## FUNCTIONALIZATION OF POLYMER NANOPARTICLES

After micelle formation, or alternatively after crosslinking, the polydiene blocks  
10 may be functionalized to form an outer layer functionalized polymer nanoparticle. The functional group is preferably selected from the group consisting of maleimide, hydroxyl, carboxy, formyl, azocarboxy, epoxide, amino, and mixtures thereof.

Without being bound by theory, it is believed that a functional group is added to the nanoparticle by reacting a compound including the desired functional group with the  
15 polydiene blocks of the nanoparticles.

The reaction is preferably carried out in a hydrocarbon solvent in an inert atmosphere at a temperature between about 100 and 250 °C. Suitable solvents includes aliphatic hydrocarbons, such as pentane, hexane, heptane, octane, nonane, decane, and the like, as well as alicyclic hydrocarbons, such as cyclohexane, methyl  
20 cyclopentane, cyclooctane, cycloheptane, cyclononane, cyclodecane, and the like. These hydrocarbons may be used individually or in combination. Of course, other known methods for conducting such reactions are contemplated.

The functional group reacts with double bonds present in the outer layer of the nanoparticles. Preferably the reaction will reach greater than 1%, more preferably greater than 10% completion.

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## STRUCTURAL MODIFICATIONS

In an alternative embodiment, an outer layer of the functionalized polymer nanoparticle is a copolymer including at least one alkenylbenzene monomer unit and at least one conjugated diene monomer unit. The copolymer may be random or ordered. Accordingly, the outer layer may include an SBR rubber. Herein throughout, references  
10 to a poly (conjugated diene) outer layer are understood to include copolymers of the type described here.

Similarly, the density of the nanoparticle may be controlled by including diblock and monoblock polymer chains in the micelles. One method for forming such polymer chains includes forming a first polymer of conjugated diene monomers in the  
15 hydrocarbon solvent. After formation of the first polymer, a second monomer is added to the polymerization, along with additional initiator. The second monomer polymerizes onto the first polymer to form a diblock polymer as well as forming a separate second polymer which is a mono-block polymer. The diblock polymer contains at least a first end block that is soluble in the dispersion solvent, preferably a conjugated diene  
20 monomer, and a second end block which is less soluble in the dispersion solvent, preferably a vinyl-substituted aromatic hydrocarbon monomer. In a preferred embodiment, a vinyl-substituted aromatic hydrocarbon is chosen which as a polymer is generally insoluble in the dispersion solvent.

The multi-block polymer preferably has  $M_w$  of about 5,000 to 10,000,000 more preferably between about 10,000 and 200,000. A typical diblock polymer will be comprised of 5 to 95% by weight conjugated diene and 5 to 95% by weight vinyl-substituted aromatic hydrocarbon, more preferably 20 to 80% by weight, and most preferably 30 to 70% by weight of each contributed monomer type. Each block preferably has  $M_w$  between about 1,000 and 10,000,000, more preferably between about 2,000 and 5,000,000.

The density of the poly (conjugated diene) outer layer of the nanoparticles may be controlled by manipulating the ratio of diblock to mono-block polymer chains. This ratio may be manipulated by altering the amount of initiator added during each step of the polymerization process. For example, a greater amount of initiator added during the polymerization of the conjugated diene monomer than added during the polymerization of the alkenylbenzene monomer would favor diblock formation over mono-block formation resulting in a high density outer layer. Conversely, a greater amount of initiator added during the polymerization of the alkenylbenzene monomer than added during the polymerization of the conjugated diene monomer would favor mono-block formation over diblock formation, resulting in a low density outer layer. The ratio of mono-blocks to diblocks can be from 1 to 99, preferably 10 to 90, more preferably 20 to 80.

## HYDROGENATION OF A NANOPARTICLE OUTER LAYER

After micelle formation, or alternatively, after crosslinking, the polydiene blocks may be hydrogenated to form a modified outer layer. A hydrogenation step may also be

carried out after functionalization of the nanoparticles. A hydrogenation step may be carried out by methods known in the art for hydrogenating polymers, particularly polydienes. A preferred hydrogenation method includes placing the crosslinked nanoparticles in a hydrogenation reactor in the presence of a catalyst. After the catalyst  
5 has been added to the reactor, hydrogen gas ( $H_2$ ) is charged to the reactor to begin the hydrogenation reaction. The pressure is adjusted to a desired range, preferably between about 10 and 3000 kPa, more preferably between about 50 and 2600 kPa.  $H_2$  may be charged continuously or in individual charges until the desired conversion is achieved. Preferably, the hydrogenation reaction will reach at least about 20%  
10 conversion, more preferably greater than about 85% conversion. The conversion reaction may be monitored by  $^1H$  NMR.

Preferred catalysts include known hydrogenation catalysts such as Pt, Pd, Rh, Ru, Ni, and mixtures thereof. The catalysts may be finely dispersed solids or absorbed on inert supports such as carbon, silica, or alumina. Especially preferred catalysts are  
15 prepared from nickel octanoate, nickel ethylhexanoate, and mixtures thereof.

The outer layer formed by an optional hydrogenation step will vary depending on the identity of the monomer units utilized in the formation of the nanoparticle outer layer, particularly the poly (conjugated diene) blocks. For example, if the poly(conjugated diene) block contains 1,3-butadiene monomer units, the resultant nanoparticle layer  
20 after hydrogenation will be a crystalline poly(ethylene) layer. In another embodiment, a layer may include both ethylene and propylene units after hydrogenation if the non-hydrogenated poly (conjugated diene) block contains isoprene monomer units. It should be noted that the non-hydrogenated poly (conjugated diene) block may contain a

mixture of conjugated diene monomer units, or even alkenylbenzene units, resulting in a mixture of monomer units after hydrogenation.

## INITIATORS

5       The present inventive process is preferably initiated via addition of anionic initiators that are known in the art as useful in the copolymerization of diene monomers and vinyl aromatic hydrocarbons. Exemplary organo-lithium catalysts include lithium compounds having the formula  $R(Li)_x$ , wherein R represents a  $C_1$ - $C_{20}$  hydrocarbyl radical, preferably a  $C_2$ - $C_8$  hydrocarbyl radical, and x is an integer from 1 to 4. Typical  
10 R groups include aliphatic radicals and cycloaliphatic radicals. Specific examples of R groups include primary, secondary, and tertiary groups, such as n-propyl, isopropyl, n-butyl, isobutyl, t-butyl, etc.

Specific examples of exemplary initiators include ethyllithium, propyllithium, n-butyllithium, sec-butyllithium, tert-butyllithium, and the like; aryllithiums, such as  
15 phenyllithium, toyllithium, and the like; alkenyllithiums such as vinylithium, propenyllithium, and the like; alkylene lithium such as tetramethylene lithium, pentamethylene lithium, and the like. Among these, n-butyllithium, sec-butyllithium, tert-butyllithium, tetramethylene lithium, and mixtures thereof are preferred. Other suitable lithium initiators include one or more of: *p*-toyllithium, 4-phenylbutyl lithium, 4-  
20 butylcyclohexyl lithium, 4-cyclohexylbutyl lithium, lithium dialkyl amines, lithium dialkyl phosphines, lithium alkyl aryl phosphine, and lithium diaryl phosphines.

Anionic initiators generally are useful in amounts ranging from about 0.01 to 60 millimoles per hundred grams of monomer charge.

## POLYMER NANOPARTICLE APPLICATIONS

A variety of applications are contemplated for use in conjunction with the nanoparticles of the present invention. Furthermore, the several mechanisms described  
5 herein for modifying the nanoparticles render them suitable for different applications. All forms of the present inventive nanoparticles are, of course, contemplated for use in each of the exemplary applications and all other applications envisioned by the skilled artisan.

## GENERAL RUBBER

After the functionalized polymer nanoparticles have been formed, they may be blended with a rubber to improve the physical characteristics of the rubber composition. Functionalized nanoparticles are useful modifying agents for rubbers because they are discrete particles which are capable of dispersing uniformly throughout the rubber  
15 composition, resulting in uniformity of physical characteristics. Furthermore, certain of the present functionalized nanoparticles are advantageous because the outer layer of poly(conjugated diene), especially vinyl-modified poly(conjugated diene), is capable of bonding with the rubber matrix due to the accessibility of the double bonds in the poly(conjugated diene).

20 The present polymer nanoparticles are suitable for modifying a variety of rubbers including, but not limited to, random styrene/butadiene copolymers, butadiene rubber, poly(isoprene), nitrile rubber, polyurethane, butyl rubber, EPDM, and the like. Advantageously, the inclusion of the present nanoparticles have demonstrated rubbers



having improved tensile and tear strength of at least about 30% over a rubber modified with non-spherical copolymers.

Furthermore, nanoparticles with hydrogenated outer layers may demonstrate improved compatibility with specific rubbers. For example, nanoparticles including a hydrogenated polyisoprene outer layer may demonstrate superior bonding with and improved dispersion in an EPDM rubber matrix due to the compatibility of hydrogenated isoprene with EPDM rubber.

Additionally, nanoparticles with copolymer surfaces may demonstrate improved compatibility with rubbers. The copolymer tails with the outer layer of the nanoparticles may form a brush-like surface. The host composition is then able to diffuse between the tails allowing improved interaction between the host and the nanoparticles.

## METAL NANOCOMPOSITE FORMATION

Functionalized nanoparticles produced in accordance with the present invention may be advantageously utilized in the formation of metal nanocomposites which can be advantageously added to rubber compositions. The formation of metal nanocomposites is preferably carried out by exposing functionalized nanoparticles to metals, preferably metals in solution. The metal is then capable of complexing with functional groups located throughout an outer layer of the functionalized nanoparticle. The poly(conjugated diene) and/or polyalkylene layer may restrict the growth of the metal nanocomposites, thus providing size control of the metal nanocomposites. Metals contemplated for use in the present invention include those known in the art as useful in the form of nanocomposites, including but not limited to Cu, Ti, Fe, Cd, Ni, Pd, and

mixtures thereof. The formation of the metal nanocomposites is preferably carried out at temperature of between about 0 and 100°C, more preferably between about 0 and 5°C. Preferred solvents useful in the formation include toluene, THF, water, alcohol, and mixtures thereof.

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## HARD DISK TECHNOLOGY

Hydrogenated functionalized nanoparticles prepared in accordance with the present invention may also find application in hard disk technology.

Disk drive assemblies for computers traditionally include a magnetic storage disk coaxially mounted about a spindle apparatus that rotates at speeds in excess of several  
10 thousand revolutions per minute (RPM). The disk drive assemblies also include a magnetic head that writes and reads information to and from the magnetic storage disk while the magnetic disk is rotating. The magnetic head is usually disposed at the end of an actuator arm and is positioned in a space above the magnetic disk. The actuator arm can move relative to the magnetic disk. The disk drive assembly is mounted on a  
15 disk base (support) plate and sealed with a cover plate to form a housing that protects the disk drive assembly from the environmental contaminant outside of the housing.

Serious damage to the magnetic disks, including loss of valuable information, can result by introducing gaseous and particulate contaminants into the disk drive assembly housing. To substantially prevent or reduce the introduction of gaseous and  
20 particulate contaminants into the disk drive housing, a flexible sealing gasket is disposed between the disk drive mounting base (support) plate and the disk drive assembly housing or cover plate. A sealing gasket is usually prepared by punching out a ring-shaped gasket from a sheet of cured elastomer. The elastomeric gasket

obtained is usually attached to the base plate of the disk drive assembly mechanically, such as affixing the gasket with screws, or adhesives. The hydrogenated nanoparticles, when compounded with a polyalkylene and a rubber, demonstrate a tensile strength comparable to that necessary in hard disk drive compositions.

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## THERMOPLASTIC GELS

Functionalized nanoparticles prepared in accordance with the present invention, whether hydrogenated or non-hydrogenated may also be blended with a variety of thermoplastic elastomers, such as SEPS, SEBS, EEBS, EEPE, polypropylene, 10 polyethylene, and polystyrene. For example, nanoparticles with hydrogenated isoprene outer layers may be blended with a SEPS thermoplastic to improve tensile strength and thermostability. These blends of thermoplastic elastomer and maleated nanoparticles would typically be extended as known in the art. For example, suitable extenders include extender oils and low molecular weight compounds or components. Suitable 15 extender oils include those well known in the art such as naphthenic, aromatic and paraffinic petroleum oils and silicone oils.

Examples of low molecular weight organic compounds or components useful as extenders in compositions of the present invention are low molecular weight organic materials having a number-average molecular weight of less than 20,000, preferable 20 less than 10,000, and most preferably limitation to the material which may be employed, the following is a list of examples of appropriate materials:

- (1) Softening agents, namely aromatic naphthenic and paraffinic softening agents for rubbers or resins;

- (2) Plasticizers, namely plasticizers composed of esters including phthalic, mixed phthalic, aliphatic dibasic acid, glycol, fatty acid, phosphoric and stearic esters, epoxy plasticizers, other plasticizers for plastics, and phthalate, adipate, sebacate, phosphate, polychlor and polyester plasticizers for NBR;
- 5 (3) Tackifiers, namely coumarone resins, coumarone-indene resins, terpene phenol resins, petroleum hydrocarbons and rosin derivative;
- (4) Oligomers, namely crown ether, fluorine-containing oligomers, polybutenes, xylene resins, chlorinated rubber, polyethylene wax, petroleum resins, rosin ester rubber, polyalkylene glycol diacrylate, liquid rubber (polybutadiene, styrene/butadiene rubber, butadiene-acrylonitrile rubber, polychloroprene, etc.), silicone oligomers, and poly-alpha-olefins;
- 10 (5) Lubricants, namely hydrocarbon lubricants such as paraffin and wax, fatty acid lubricants such as higher fatty acid and hydroxy-fatty acid, fatty acid amide lubricants such as fatty acid amide and alkylene-bisfatty acid amide, ester lubricants such as fatty acid-lower alcohol ester, fatty acid-polyhydric alcohol ester and fatty acid-polyglycol ester, alcoholic lubricants such as fatty alcohol, polyhydric alcohol, polyglycol and polyglycerol, metallic soaps, and mixed lubricants; and,
- 15 (6) Petroleum hydrocarbons, namely synthetic terpene resins, aromatic hydrocarbon resins, aliphatic hydrocarbon resins, aliphatic or alicyclic petroleum resins, polymers of unsaturated hydrocarbons, and hydrogenated hydrocarbon resins.
- 20

Other appropriate low-molecular weight organic materials include latexes, emulsions, liquid crystals, bituminous compositions, and phosphazenes. One or more of these materials may be used in as extenders.

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## TIRE RUBBER

One application for functionalized nanoparticle containing rubber compounds is in tire rubber formulations.

Vulcanizable elastomeric compositions of the invention may be prepared by mixing a rubber, a functionalized nanoparticle composition, with a reinforcing filler  
10 comprising silica, or a carbon black, or a mixture of the two, a processing aid and/or a coupling agent, a cure agent, and an effective amount of sulfur to achieve a satisfactory cure of the composition.

Preferred rubbers are conjugated diene polymers, copolymers, or terpolymers of conjugated diene monomers and monovinyl aromatic monomers, can be utilized as 100  
15 parts of the rubber in the tread stock compound, or they can be blended with any conventionally employed treadstock rubber which includes natural rubber, synthetic rubber and blends thereof. Such rubbers are well known to those skilled in the art and include synthetic polyisoprene rubber, styrene-butadiene rubber (SBR), styrene-isoprene rubber, styrene-isoprene-butadiene rubber, butadiene-isoprene rubber,  
20 polybutadiene, butyl rubber, neoprene, acrylonitrile-butadiene rubber (NBR), silicone rubber, the fluoroelastomers, ethylene acrylic rubber, ethylene-propylene rubber, ethylene-propylene terpolymer (EPDM), ethylene vinyl acetate copolymer, epichlorohydrin rubber, chlorinated polyethylene-propylene rubbers, chlorosulfonated

polyethylene rubber, hydrogenated nitrile rubber, tetrafluoroethylene-propylene rubber and mixtures thereof.

Examples of reinforcing silica fillers which can be used in the vulcanizable elastomeric composition include wet silica (hydrated silicic acid), dry silica (anhydrous silicic acid), calcium silicate, and the like. Other suitable fillers include aluminum silicate, magnesium silicate, and the like. Among these, precipitated amorphous wet-process, hydrated silicas are preferred. Silica can be employed in the amount of about one to about 100 parts per hundred parts of the elastomer, preferably in an amount of about 5 to 80 phr and , more preferably, in an amount of about 30 to about 80 phrs. The useful upper range is limited by the high viscosity imparted by fillers of this type. Some of the commercially available silica which can be used include, but are not limited to, HiSil® 190, HiSil® 210, HiSil® 215, HiSil® 233, HiSil® 243, and the like, produced by PPG Industries (Pittsburgh, PA). A number of useful commercial grades of different silicas are also available from DeGussa Corporation (e.g., VN2, VN3), Rhone Poulenc (e.g., Zeosil® 1165MP), and J.M. Huber Corporation.

Including surface functionalized nanoparticles in silica containing rubber compositions has been shown to decrease the shrinkage rates of such silica containing rubber compositions. Maleated nanoparticles may be compounded in silica compositions in concentrations up to about 30 wt% of the total composition, more preferably up to about 40 wt%, most preferably up to about 50 wt%.

The rubber can be compounded with all forms of carbon black, optionally additionally with silica. The carbon black can be present in amounts ranging from about one to about 100 phr. The carbon blacks can include any of the commonly available,

commercially-produced carbon blacks, but those have a surface area of at least 20 m<sup>2</sup>/g and, or preferable, at least 35m<sup>2</sup>/g up to 200m<sup>2</sup>/g or higher are preferred. Among useful carbon blacks are furnace black, channel blacks, and lamp blacks. A mixture of two or more of the above blacks can be used in preparing the carbon black products of the invention. Typical suitable carbon black are N-110, N-220, N-339, N-330, N-352, N-550, N-660, as designated by ASTM D-1765-82a.

Certain additional fillers can be utilized including mineral fillers, such as clay, talc, aluminum hydrate, aluminum hydroxide and mica. The foregoing additional fillers are optional and can be utilized in the amount of about 0.5 phr to about 40 phr.

Numerous coupling agents and compatibilizing agents are known for use in combining silica and rubber. Among the silica-based coupling and compatibilizing agents include silane coupling agents containing polysulfide components, or structures such as, for example, trialkoxyorganosilane polysulfides, containing from about 2 to about 8 sulfur atoms in a polysulfide bridge such as, for example, bis-(3-triethoxysilylpropyl) tetrasulfide (Si69), bis-(3-triethoxysilylpropyl) disulfide (Si75), and those alkyl alkoxysilanes of the such as octyltriethoxy silane, hexyltrimethoxy silane.

It is readily understood by those having skill in the art that the rubber composition would be compounded by methods generally known in the rubber compounding art, such as mixing the various vulcanizable polymer(s) with various commonly used additive materials such as, for example, curing agents, activators, retarders and accelerators, processing additives, such as oils, resins, including tackifying resins, plasticizers, pigments, additional fillers, fatty acid, zinc oxide, waxes, antioxidants, anti-ozonants, and peptizing agents. As known to those skilled in the art, depending on the

intended use of the sulfur vulcanizable and sulfur vulcanized material (rubbers), the additives mentioned above are selected and commonly used in the conventional amounts.

Specifically, the above-described functionalized nanoparticle containing rubber compounds are contemplated for use in rubber compounds used to make tire treads and side walls due to the enhanced reinforcement capabilities of the present nanoparticles. The higher dynamic modulus ( $G'$ ) and its lower temperature dependence along with the lower hysteresis values at high temperature leads to the improved cornering, handling, dry, snow, and wet traction, rolling resistance, dispersion, and aging properties of the resultant tire compositions. Improved aging properties, thermal aging (high temperature) or mechanical aging (static or dynamic deformation cycles), include retention of the  $G'$  modulus, hysteresis, mechanical strengths, etc. Tin-functionalized nanoparticles are especially suited for use in tire compositions. Nanoparticles including a copolymer outer layer are also suitable for use in such tire compositions, because the longer copolymer chains in the outer layer leads to greater diffusion of the host rubber composition into the outer layer of the nanoparticle.

## ENGINEERING PLASTICS AND OTHERS

Similarly, the functionalized nanoparticles can be added into typical plastic materials, including polyethylene, polypropylene, polystyrene, polycarbonate, nylon, polyimides, etc. to for example, enhance impact strength, tensile strength and damping properties.



Of course, the present inventive functionalized nanoparticles are also suited to other presently existing applications for nanoparticles, including the medical field, e.g. drug delivery and blood applications, information technology, e.g. quantum computers and dots, aeronautical and space research, energy, e.g., oil refining, and lubricants.

5

#### ENGINE MOUNT, ETC.

Another application for such rubbers is in situations requiring superior damping properties, such as engine mounts and hoses (e.g. air conditioning hoses). Rubber compounds of high mechanical strength, super damping properties, strong resistance to  
10 creep are demanded in engine mount manufacturers. In engine mount, a rubber, because it sits most of its life in a packed and hot position require rubbers of very good characteristics. Utilizing the functionalized nanoparticles within selected rubber formulations can improve the characteristics of the rubber compounds.

The following examples are provided to help illustrate the present invention. The  
15 examples are not intended to limit the scope of the invention as defined by the appended claims.

#### EXAMPLES

##### Example 1. Synthesis of PBD-PS micelle polymers

20 All of the polymers were prepared by anionic polymerization in hexane through three stages. In the first stage, butadiene (BD) and styrene (ST) were charged into the reactor which the polymerization was initiated with butyl lithium (BuLi) and the microstructure was controlled by adding oligomeric oxolanyl propane polar randomizer

(OOPS). The polymer molecular weight (MW) was controlled by adjusting the ratio of the monomers and the level of initiator used. After nearly all of the monomers were consumed in the first stage, additional styrene was charged for polymerization for certain period of time to form the micelle PS core in the second stage. The 50 mL of the divinyl benzene (DVB) was charged into the reactor in the third stage to crosslink the micelle PS domain. The stoichiometry of the initiator, modifier, monomers, and DVB used to prepare these micelle polymers are detailed in Table 1. The polymerization temperature was maintained at 57 °C in all of the stages. All of these polymers were isolated by the addition of a mixture of acetone and isopropanol in a volume ratio of 95% to 5%. Tet-butyl-2 hydroxy toluene (BHT) was then added into the polymer as an antioxidant.

Table 1. Stiochimetry of the initiator, modifier, monomers, and DVB employed for polymerization Process.

Polymerization Stage	1 <sup>st</sup> Stage			2 <sup>nd</sup> Stage	3 <sup>rd</sup> Stage
	1.68 M BuLi	1.6 M OOPs	22 wt% butadiene in hexane	33 wt% styrene in hexane	DVB
Example 1	5.0 mL	2.5 mL	1.02 kg	0.68 kg	50 mL

Example 2: Synthesis of Maleated functionalized PBD-PS micelle polymers (M-PBD-PS)

Sixty grams of maleic anhydride in 300ml of DTDP oil under the continuous purge of nitrogen gas were heated to 170 °C. 500 mL of the hexane solution that contained 10% of the product from Example 1, PBD-PS, was slowly added into the maleic anhydride solution in two hours. After the completion of the addition of PBD-PS,

it was heated to 180 °C for 30 minutes before dropping into toluene solvent and isolated with isopropanol. 2.8 wt% of maleic anhydride was found covalently bonded to the PBD layer of the M-PBD-PS nanoparticles, as confirmed by <sup>13</sup>C NMR analysis. The maleated nanoparticles are not soluble in hexane.

- 5            The characterization of these polymers include  $M_w$ , molecular weight distribution (MWD), polymer microstructure, and  $T_g$  are displayed in Table 2.

TABLE 2: Characterization data of nanoparticles from Examples 1 and 2

Polymer	SBR-Duradiene 715	Example 1	Example 2
$M_w$ of the polymer		1,026,960	1,026,960
$M_w$ of single PS in micelle core	N/A	50,000	50,000
MWD	N/A	1.11	1.11
Cis BR%	23.5	18	18
Trans BR%	47	60	60

- 10        Examples 3-5: Compounding of PBD-PS AND M-PBD-PS nanoparticles

#### Rubber compound Preparation

- Three stocks of rubber compounds were prepared using the formulation and mixing conditions shown in Tables 3 and 4. Seventy phr of SBR Duradiene 715 and thirty parts of polybutadiene were used to prepare example 3, the control. An addition  
 15    10 phr of PBD-PS or M-PBD-PS was added to example 3 to form examples 4 and 5. The composition of the polymers used for each of the examples is listed in Table 5. The final stock was sheeted and then was subsequently molded at 171 °C for 15 minutes.

Table 3: Formulation used to prepare rubber compounds of Examples 3-5

Component	Concentration (phr)
SBR (Duradiene 715)	70.00
PBD	30.00
5 Nanoparticle	Varied
Silica (HiSil 190)	65.00
Wax	1.50
Disulfide silane	5.73
Antioxidant [N-(1,3-dimethylbutyl)-N'-phenyl- <i>p</i> -phenylene-	0.85
10 diamine]	
Aromatic Process Oil	16.25
Sulfur	1.30
Steric acid	2.00
Accelerator [N-cyclohexyl-2-benzothiasole-sulfenamide]	1.50
15 Diphenyl guanidine	0.50
Zinc oxide	2.00

20 Table 4: The mixing conditions used to prepare the rubber compounds of Examples 3-5

Mixer	310 g Brabender
Agitation Speed	60 rpm
Master Batch Stage	
Initial Temperature	100 °C
25                      0 seconds	Charging polymers and nanoparticles (where included)
30 seconds	Charging silica and all pigments
5 minutes	Drop
Drop Temperature	170 °C
30 Remill 1 Batch Stage	
Initial Temperature	70 °C
0 seconds	Charging remilled stock and silane
Drop Temperature	145 °C
Final Batch Stage	
35      Initial Temperature	90 °C
0 seconds	Charging remilled stock
30 seconds	Charging curing agent and accelerators
Drop Temperature	105 °C

40

Table 5: SBR, BR, PBD-PS and M-PBD-PS used to prepare examples 3-5

Example	SBR-phr	BR-phr	PBD-PS phr	M-PBD-PS phr
3 (control)	70	30	0	0
4	70	30	10	0
5	70	30	10	10

The processing of the rubber compound was evaluated by examining the compound Mooney and scorch data along with the curing characteristic data. The Mooney viscosity and the curing characteristics of the uncured stocks are shown in Table 6. Mooney viscosity measurements were conducted at 130 °C using a large rotor. The Mooney viscosity data was recorded as the torque when rotor has rotated for 4 minutes. The sample was preheated at 130 °C for 1 minute before the rotor starts.  $T_5$  is the time required to increase 5 Mooney units during the Mooney-scorch measurement. It is used as an index to predict how fast the compound viscosity will rise during processing such as extrusion processing.  $T_{S2}$  and  $T_{90}$  are the time when torque rises to 2% and 90% of the total increase during curing characterization experiment at 171 °C. They are used to predict the speed of the viscosity build-up ( $T_{S2}$ ) and the curing rate during the curing process.

Table 6: Mooney scorch and curing characteristics

Example	ML <sub>1+4</sub> @ 130 °C	$T_5$ scorch @ 130 °C (minutes)	$T_{S2}$ @ 171 °C (minutes)	$T_{90}$ @ 171 °C (minutes)
3 (control)	69.31	2900	0.84	20.94
4	70.88	3041	2.01	21.4
5	77.19	N/A	1.22	26.22

The Scorch  $T_5$ ,  $T_{S2}$ , and curing characteristics of examples 4-5 were found to be comparable to the control (example 3). With the exception of the higher compound Mooney found for example 3, it is apparent that addition of ABR-PS polymer in rubber compounds will not affect the processing. The higher Mooney in silica compound can

be adjusted by use of processing aids or shielding agents. Therefore, it is not expected to encounter apparent processing problems with these stocks containing nanoparticles.

#### Mechanical Properties:

##### 5 Tensile mechanical properties:

The tensile mechanical properties of Examples 3-5 are listed in Table 7. The tensile mechanical properties were measured using the standard procedure described in ASTM-D 412 at 25 °C. The tensile test specimens are round rings with a dimension of 0.05 inches in width and 0.075 inches in thickness. A specific gauge length of 2.54  
10 cm is used for the tensile test.

Table 7: Tensile mechanical properties at 25 °C

Example	M50 (Mpa)	M300 (Mpa)	Strength, Tb (Mpa)	Elongation at break, Eb, %	Toughness (Mpa)
3 (control)	1.39	9.49	14,78	409	26
4	1.43	8.81	15.47	450	30.56
5	1.51	8.39	14.64	454	30.04

Improvements in the tensile mechanical properties, including elongation at break  
15 (10%) and tensile toughness (15%), by addition of nanoparticles are evident. However, at an elevated temperature of 100 °C, the improved mechanical properties found in PBD-PS examples at room temperature are not reproducible (as seen in Table 8, below). By replacing the PBD-PS nanoparticles with M-PBD-PS, better mechanical properties were obtained, as shown in Table 8.

Table 8: Tensile mechanical properties at 100 °C

Example	M50 (Mpa)	M300 (Mpa)	Strength, Tb (Mpa)	Elongation at break, Eb, %	Toughness (Mpa)
3 (control)	1.15	N/A	7.48	289	10.05
4	1.14	N/A	7.13	299	10.14
5	1.14	6.69	7.95	348	13.23

The superior elevated temperature mechanical properties were also confirmed by the tensile mechanical properties obtained from dumbbell shape samples (Table 9).

5 Table 9: Tensile mechanical properties at 100 °C obtained from tensile test on dumbbell-shaped samples

Example	M50 (Mpa)	M300 (Mpa)	Strength, Tb (Mpa)	Elongation at break, Eb, %	Toughness (Mpa)
3 (control)	1.94	7.72	8.09	315	13.93
4	1.85	6.89	8.01	355	15.71
5	1.92	6.82	8.35	379	17.71

#### Dynamic Mechanical Storage Modules (G')

The dynamic viscoelastic storage modulus (G') of the cured stocks in shown in  
 10 Figures 1 and 2, where data from Figure 1 was obtained from temperature sweep experiments (TS) and data from Figure 2 was obtained from 50 °C strain sweeps. Temperature sweep experiments were conducted with a frequency of 31.4 rad/sec using 0.5% strain for temperatures ranging from -100 °C to 100 °C. A frequency of 3.14 rad/sec was used for strain sweep which is conducted at 50 °C with strain sweeping  
 15 from 0.25% to 14.75%.

Improvements of G' at over a range of measured temperatures and applied strain levels of examples with M-PBD-PS over the PBD-PS and control examples are seen in Figures 1 and 2.

## Wear Resistance

The wear resistance of the test samples was evaluated by weighing the amount of wear using the Lambourn test. The wearing index was obtained from the ratio of the weighty loss of the control to that of the tested sample. Samples with higher wear indices have better wear resistance properties. Samples used for Lambourn test are circular donuts with the following approximate dimensions: 0.9 and 1.9 inches in inside and outside diameter, and 0.195 inches in thickness. Test specimens are placed on an axle and run at a slip ratio of 65% against a driven abrasive surface.

The degraded abrasion resistance found in the PBD-PS added example can be improved by to the control level by replacing it with the M-PBD-PS. This can clearly be seen in the abrasion resistance data shown in Table 10.

Table 10: Abrasion Resistance Data

Example	Abrasion resistance index
3 (control)	100
4	88
5	97

### Example 6. Preparation of PBD-PS Nanoparticles

A 7.5 L polymerization reactor was used for the preparation. The reactor was first charged with 517 g of hexane, followed by 1.0 kg butadiene/hexane blend (22.0 wt% of butadiene). The reactor was then heated to 57 °C. After the temperature stabilized, the reactor was first charged with 2.5 mL of 1.6 M OOPS. The polymerization was initiated with 5.0 mL of a 1.68 M solution of butyl lithium in hexane. The batch temperature was maintained at 57 °C for the duration of the polymerization. After 2 hours (when the reaction was finished), the reactor was charged with 680 g of



styrene/hexane blend (33 wt% of styrene). After additional two-hour reaction, the reactor was charged with 1.8 kg of Hexane. After another additional 20 minutes, the reactor was charged with 50 mL of divinyl benzene. The temperature was maintained at 57 °C for two-hours, and a small amount of the product was taken for GPC analysis.

5 The GPC analysis of the product showed that the micelle polymer had a number average molecular weight of 1,027,000. The polydispersity of the molecular weight was 1.11. The conversion of the reaction is about 100%. The NMR analysis showed that the product contains 50% of butadiene and 50% of styrene. The polybutadiene contains 22% cis, 18% trans and 60% vinyl structures. The product was dropped into  
10 isopropanol, precipitated, and drum dried. TEM analysis (Figure 3) showed nano-sized particles.

#### Example 7. Preparation of Maleated Particle Polymers

A 2000 mL three-neck round-bottom flask was used for the preparation. The  
15 middle neck was connected with a mechanical string motor. The left neck was used to charge various materials. The right neck was open for N<sub>2</sub> purging and thermometer placing. To the flask, 300 mL of DTDP oil (C.P. Hall) and 60 g of maleic anhydride (Aldrich) were charged. The flask was placed into a silicon oil bath and heated to 170 °C. After temperature was stabilized, 500 mL of the hexane solution containing 10% of  
20 the product from Example 6 was added in droplet fashion into the flask. The charging speed was very slow and the process took about 2 hrs. After charging, the flask was maintained at 180 °C for half hour. The product was dropped into toluene and precipitated via addition of isopropanol. The product was washed five times with

isopropenol. TEM analysis (Figure 4) showed nano-sized particles.  $^{13}\text{C}$  NMR analysis shows that the BR shell of particles contains about 2.8 wt% covalently bonded maleic anhydride. The product was insoluble in hexane.

#### 5 Example 8. Preparation of Copper Ion-Polymer Particle Composite

Three 40 mL bottles were charged according to the following descriptions. Those bottles were then identified as bottle A, B, and C, respectively. The material inside those bottles was named accordingly as material A, B, and C.

A) 0.5 g of the products from example 7 was added into 15 g THF solvent.  
10 After vigorous stirring for half hour, the maleated particles were dissolved. The solution was completely transparent.

B) 0.5 g of the products from example 7 was added into 15 g toluene solvent. After vigorous stirring for half hour, the maleated particles were dissolved. The solution was completely transparent.

15 C) 0.5 g of  $\text{CuAc}_2$  was added into a 15 g of THF solvent. After vigorous stirring for half hour, the  $\text{CuAc}_2$  was dissolved. The solution was transparent to light.

The bottle B was then charged with 1.5 mL of solution from bottle C. The resulting solution was placed in a vacuum oven at 50 °C. Further drying of the product under vacuum yielded a polymer micelle-Cu complex film. The film is dark blue, but  
20 transparent to light. In addition, the resulting film is insoluble in toluene, indicating that a new polymer complex was formed.

#### Example 9. Preparation of $\text{Cu}_2\text{S}$ -Polymer Particle Composite

A bottle was charged with 1.5 mL of solution from bottle C. The resulting solution was dark blue color.  $\text{H}_2\text{S}$  gas was bubbled through the solution to fully convert the Cu ions to  $\text{CuS}$ . The solution was purged with  $\text{N}_2$  to remove excess  $\text{H}_2\text{S}$ . The resulting solution was dark colored, with no evidence of macroscopic precipitation of  $\text{CuS}$  from the solution. This indicated the  $\text{CuS}$  particles formed are nano-scaled. The resulting solution was placed in a vacuum oven at  $50\text{ }^\circ\text{C}$ . Further drying of the product under vacuum yielded a polymer micelle- $\text{CuS}$  nanocomposite film. The materials was black, but transparent to light.

#### Example 10. Preparation of Azocarboxylated Particle Polymers

A 2000 mL three-neck round-bottom flask was used for the preparation. The middle neck was connected with a mechanical stirrer motor. The left neck was used to charge various materials. The right neck was opened to  $\text{N}_2$  purging and the thermometer placed. 200 mL of DTDP oil (from C.P. Hall) and 70 g of diisopropyl azocarboxylate (from Aldrich) were charged to the flask. The flask was placed into a silicon oil bath and heated to  $90\text{ }^\circ\text{C}$ . After the temperature stabilized, 660 g of the toluene solution containing 10% of the product from Example 6 was added in droplet fashion into the flask. The charging speed was slow, over about 2 hrs. After charging, the flask was heated to  $100\text{ }^\circ\text{C}$  and held at that temperature for two hours. The flask was then heated to  $110\text{ }^\circ\text{C}$  and held at that temperature for another two hours. Finally, the flask was heated to between  $120\text{ }^\circ\text{C}$  and  $125\text{ }^\circ\text{C}$  and held at that temperature for three hours.

The product was dropped into hexane, and a light-yellow product precipitated from the hexane solution. The product was washed five times with hexane. GPC analysis of the product, using polystyrene/THF as the standard, showed that the polymer had a number average molecular weight ( $M_n$ ) of 857,900. The polydispersity of the molecular weight was 1.09.  $^{13}\text{C}$  NMR analysis C=O and styrene showed that the product contained about 86.7 parts of chemically bonded diisopropyl azocarboxylate over one hundred parts (by weight) of the polymer of example 6. The product was soluble in methanol, ethanol, isopropanol, THF, chloroform, and toluene, but not soluble in hexane and cyclohexane.

10

#### Preparation of Nano-sized Copper Sulfide (CuS) Particles

Three 40 mL bottles were charged according to the following descriptions. The bottles were then named as bottle D, E, and F respectfully. The material inside those bottles was named accordingly as material D, E, and F.

15 D) 0.5 g of the products from example 10 was added into 15 g toluene solvent. After vigorous stirring for half hour, the azocarboxylated particles were dissolved resulting in a transparent solution.

E) 0.5 g of  $\text{CuAc}_2$  (from Aldrich) was added into a 15 g of THF solvent. After vigorous stirring for half hour, the  $\text{CuAc}_2$  was dissolved resulting in a transparent to light  
20 solution.

F) 15 g pure toluene.

Example 11.

Bottle D was charged with 1.5 mL of solution from bottle E. The resulting solution was dark blue color. H<sub>2</sub>S gas (Aldrich) was bubbled through the solution to fully convert the Cu ions to CuS. The solution was purged with N<sub>2</sub> to remove excess H<sub>2</sub>S. The resulting solution is dark colored, with no macroscopic precipitation of CuS from the solution for a period of one month, indicating formation of nanoscale CuS particles complexed to the nanoparticles of Example 10. The resulting solution was placed in a vacuum oven at 50 °C. Further drying of the product under vacuum yielded a polymer micelle-CuS nanocomposite film. The film was black, but transparent to light.

#### 10 Example 12.

Bottle F was then charged with 1.5 mL of solution from bottle E. The resulting solution was dark blue color. H<sub>2</sub>S gas was then bubbled through the solution to fully convert the Cu ions to CuS. The solution was purged with N<sub>2</sub> to remove excess H<sub>2</sub>S. The resulting solution showed macroscopic precipitation of CuS from the solution immediately during the process.

#### Example 13.

The transmission electron microscopy (TEM) analysis was taken on the solution in bottle D after the H<sub>2</sub>S treatment. The solution was further diluted with the toluene solvent to about 10<sup>-5</sup> wt%. A drop of the diluted solution was then coated on a graphed copper micro-grid. After the solvent was evaporized, the screen was examined by TEM. The results showed that the polymer synthesized is a particle-like material and the average particle size was about 40 nm (Figure 5). The CuS nano particles existed

inside of each polymer particle and the average particle size of CuS crystals was 5 to 10 nm (Figure 6). It is noted that the two pictures were taken at the same position, but the focus depths were different.

## 5 Preparation of Azocarboxylated Particle Polymers

Example 14. A 2000 mL three-neck round-bottom flask was used for the preparation. 740 g of the toluene solution containing 10% of the product from Example 6 and 100 g of diisopropyl azocarboxylate (from Aldrich) were added to the flask together. The flask was purged with N<sub>2</sub> for 0.5 hours. The flask was then heated to 115 °C and held at that temperature for seven hours. The product was dropped into hexane, and a light-yellow product was precipitated. The product was washed five times with hexane. GPC analysis of the product, using polystyrene/THF as the standard, showed that the polymer had a M<sub>n</sub> of 858,200. The polydispersity of the nanoparticles was 1.10 <sup>13</sup>C NMR analysis showed the product contained about 121 parts of covalently bonded diisopropyl azocarboxylate over one hundred parts (by weight) of the polymers of Example 6. The product was soluble in methanol, ethanol, isopropanol, THF, chloroform, and toluene, but was insoluble in hexane and cyclohexane.

## Preparation of Nano-sized Cadmium Sulfide (CdS) Particles

20 Three 40 mL bottles were charged according to the following description. The bottles were then named as bottle G, H, and I, respectively. The material inside those bottles was named accordingly as material G, H, and I.

G) 0.5 g of the products from example 14 was added to 15 g toluene solvent. After vigorous stirring for half hour, the azocarboxylated particles were dissolved, and the solution was completely transparent.

H) 0.5 g of CdAc (Aldrich) was added to 15 g of MeOH solvent. After  
5 vigorous stirring for half hour, the CdAc was dissolved resulting in a transparent and colorless solution.

I) 15 g pure toluene.

#### Example 15.

10 Bottle G was charged with 1.5 mL of solution from bottle H. H<sub>2</sub>S gas was bubbled through the solution to fully convert the Cd ions to CdS. The solution was purged with N<sub>2</sub> to remove excess of H<sub>2</sub>S. The resulting solution was yellow, with no macroscopic precipitation of CdS from the solution for a period of one month, indicating formation of nano-scaled CdS particles complexed to the nanoparticles of Example H.  
15 The resulting solution was placed in a vacuum oven at 50 °C. Further drying of the product under vacuum yielded to a polymer nanocomposite film. The film was yellow colored, but transparent to light.

#### Example 16.

20 Bottle I was charged with 1.5 mL of solution from bottle H. H<sub>2</sub>S gas was bubbled through the solution to fully convert the Cd ions to CdS. The solution was purged with N<sub>2</sub> to remove excess H<sub>2</sub>S. The resulting solution showed macroscopic precipitation of the yellow CdS from the solution immediately during the process.

The invention has been described with reference to the exemplary embodiments. Modifications and alterations will occur to others upon reading and understanding the specification. The invention is intended to include such modifications and alterations insofar as they come within the scope of the disclosure and claims.